Multi-source Aeroacoustic Noise Prediction Method

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Introduction

- Trend to reduce engine displacement while increasing break power by turbo charging engines

- Traditionally GT Power and Wave are used for predicting engine order content when developing exhaust systems

- Our company has had mixed results using a combination of RANS/Vnoise

- Rule of thumb; maximum mach number < 0.25

- The latter inherently assumes aero-acoustic sources are solely dependent on Mach number
Test data of Sound power against Mach number for pipes with an outer diameter of 1.75”

Looking at Mach Numbers in the tailpipe does not alleviate all concern for flow noise
Review of available aero-acoustics methods

- **DNS**
  Predict all eddie scales directly to solve the Navier-Stokes equations

- **RANS**
  The averaged version of the Navier-Stokes equation are solved along with another equation to represent all turbulent scales.
  Only the effect of eddies on the mean flow are captured

- **Vnoise**
  The use of a RANS simulation as an input into a noise propagation software and captures the propagation to the desired microphones.
Multi-source Aeroacoustic Noise

- RANS with an acoustic analogy seems to offer the best solution

- Initial objective was to develop a methodology which is within 3 dB of measurements and create a tailpipe design guideline

- Chosen to use the Proudman acoustic analogy
Background Fluid Dynamics

**Pipe bend**

- The first is caused by flow separation around pipe bends

**Jet noise**

- The second is commonly known as “jet noise”
Proudman analogy (Lilley)

- The acoustic power, AP per unit volume (W/m\(^3\))
  \[ AP = \alpha \rho \frac{u^3}{T} \frac{s}{a_0} \]  

- The total acoustic power per unit volume can be reported in dB:
  \[ AP(dB) = 10\log\left(\frac{AP}{P_{ref}}\right) \]  

- Where \(P_{ref}\) is the reference acoustic power; 10e-12 W/m\(^3\)

- Using the classical summation for multiple acoustic sources [2], the total sound power can be found
  \[ SPL_T = 10\log_{10}\left(\sum_{i=1}^{n} 10^{\frac{SPL_i}{10}}\right) \]  

- The largest total is when both sources are the same value and thus the total is 3 dB louder than the single source.
Adjusted Proudman sources

Proudman adjusted wake

\[ AP(\text{dB}) = 10\log\left( \frac{AP}{P_{\text{ref}}} \right) + C_1 \]  \[3\]

Proudman adjusted bend

\[ AP(\text{dB}) = 10\log\left( \frac{AP}{P_{\text{ref}}} \right) + C_2 \]  \[4\]
RANS CFD Methodology

- 2mm cell size in the wake
- Volume refinement around the pipe bend
- A low Reynolds mesh
- The K-omega SST model
Typical flow for a 90° bend

Radial flow magnitude can be 2/3 of the axial mean flow so the secondary flow can be quite strong.
Typical flow for a 90° bend

Velocity

Turbulent Kinetic Energy

Proudman Acoustic Power

Proudman Acoustic Power
Parts tested

Do: Outer pipe diameter
r: Inner pipe radius
Rc: Radius of curvature of bend
Rc/r: Bend ratio

Straight pipes

Do: 55 mm
Do: 50 mm
Do: 45 mm

Bent pipes

Do: 57 mm, Rc/r: 3.2
Do: 45 mm, Rc/r: 4.2
Do: 45 mm, Rc/r: 3.6
Do: 45 mm, Rc/r: 3.0
Comparison of test data to Proudman analogy
Straight pipe Do: 45mm

With the Proudman correction [3], the correlation is excellent.
Comparison of test data to Proudman analogy
For all straight pipes

Proportional relationship between sound power and Mach Number for straight pipes
Comparison of test data to Proudman analogy
For the bent pipes

Using Proudman with correction [3] and integrating over the whole region (Total), the sound power is always underpredicted.

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Average $\Delta \sim 2$ dB
Comparison of test data to Proudman analogy
For the bent pipes

Integrating separately for each source region and applying an adjustment to the bend source strength [4] the average difference was reduced to less than 1 dB
CFD predictions for a range of sizes available from our prototype shop

Populate the range of sizes from our prototype shop, now we can create a design guideline to reduce flow noise based upon bend ratio.
Conclusions

- Aero-acoustics prediction within 1 dB using the Proudman analogy and two small correction factors
- Quantifying the contribution of each source is easy to implement via field functions
- Design guideline was populated so that we can minimize aero-acoustic noise
Future

- Additional sizes from our prototype shop need to be added to the design chart

- Further testing required to understand how the distance between the pipe bend and tailpipe exit affect the sound power

- INCE paper, submission pending